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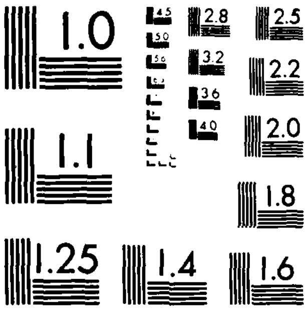

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by

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SUMMARY

The concept of displaying the accumulation of fatigue damage against time into flight is described. Two distinct modes of presentation are described: one called 'the ground mode' is suitable for use in ground analysis of load time histories and the other designated 'the snapshot mode' can be used in the real time environment. Examples drawn from operational aircraft loads data are used to demonstrate the usefulness of the display. The damage accumulation plot permits a ready identification of those flight conditions/flight activities which give rise to substantial fatigue damage. Thus it can be used to identify the structurally relevant flight data and so reduce the quantity of data that needs to be analysed in an operational loads measurement programme. It has many uses in the field of loads data analysis and is of particular importance in advanced fatigue load monitoring systems, fleet management from a fatigue standpoint and in the specification of fatigue test loading sequences.

Departmental Reference: Materials/Structures 24

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1 INTRODUCTION

As the in-service lives of aircraft grow there is a continuing need to assess the life of the structure against a demonstrated (or assumed) life of a typical specimen. For this to be achieved accurately, the spatial and temporal distribution of loads on the structure in service must be known so that a representative fatigue test can be devised. Very often the fatigue test proceeds on the basis of calculated loading distributions built up from assumed usage patterns. Provided this procedure does not yield test loading conditions which differ markedly (in a structural sense) from the actual loading patterns incurred in service, then an assessment of the consumption of fatigue life in service is possible from the demonstrated fatigue performance of the structure under test. To monitor the accumulation of fatigue damage on a service aircraft, each aircraft should ideally carry a loads monitoring system which records the loading environment experienced by all fatigue critical parts of the vehicle during a flight in as much detail as is necessary.

In the early 1950s, when this procedure was first implemented, attention was focussed on the wing centre section where there had been a number of fatigue failures. The loads in this part of the main wing structure are reasonably well correlated with the normal acceleration at the cg and so a useful indication of the loading environment can be obtained from a study of this parameter. Statistics of the loading environment were logged by a simple counting accelerometer, with special levels and thresholds, known as the Fatigue Load Meter. This instrument is carried by virtually all RAF aircraft and in addition to its fatigue monitoring role has been used to furnish usage data of value in the design of new aircraft and in the specification of fatigue test loading sequences. The number of counts at each load level are read at the end of each sortie. (For a few aircraft this is supplemented by readings at intervals during the flight.) These data, in conjunction with the fatigue meter formula, provide estimates of fatigue damage at some point of the airframe which is critical in fatigue. An immediate indication of the damage accrued is therefore readily available. The sortie damage can be linked to some form of documentary sortie coding and fleet fatigue life management practised by limiting the frequency of structurally severe sorties. As important is the ready indication of the relative damage between different flights of the same nominal type. The overall measure gives, however, no indication of the most fatigue damaging phases of the flight - and offers little scope for fleet management by planning of sortie content or modifying individual manoeuvres.

For many parts of the aircraft it is difficult, if not impossible, to relate the local structural loads to fatigue meter statistics of cg normal acceleration. Recently fatigue failures of other major components of aircraft have drawn attention to the need to produce reliable estimates of fatigue life consumption throughout the airframe. This becomes more imperative for ACT aircraft when the loading environment can be expected to be very different from that previously experienced. Similarly a change of role during the course of an aircraft's life can lead to a loading environment significantly different from that expected at the design stage. Many operational loads data acquisition programmes have been initiated in the recent past, covering a wide variety of aircraft types, to quantify the loading environment during squadron usage since it is recognised that this may differ substantially from that during flight test. These programmes incorporate strain gauge installations giving a direct indication of the loading environment, as seen by the structure, from which an assessment of fatigue damage, and the reasons for it, can be made. The fatigue meter produces some 8 numbers per flight but the data acquisition programmes referred to above yield up to 500000000 words of information per flight! The loads data analyst clearly needs a method of identifying which bits of the data are worthy of detailed study. In this respect the user of the aircraft and the analyst of operational loads data are as one - they both need a readily usable method of pinpointing those regions of the flight which contribute substantially to fatigue damage. The user wishes to plan his usage of the available life of the aircraft and the loads analyst to provide accurate estimates of fatigue damage for these critical events.

This Report describes a technique of displaying the structural data so that fatigue damaging portions of the flight are readily identified and their severity easily assessed. During the damage calculation a record of the time into flight is kept which is used to produce a plot of the accumulation of fatigue damage against time. Flight periods incurring differing constant rates of fatigue damage are readily identified as are isolated large loads. Any consistent pattern in either of these features from flight to flight can be established by visual examination of a few pieces of paper. From such information it is possible that more representative fatigue test loading sequences could be devised thus increasing the realism of the test. Used in conjunction with other parametric data describing the flight condition and aircraft response, the display technique offers a unique opportunity for fleetwide aircraft management from a fatigue point of view.

Two modes of presentation of accumulation of fatigue damage are developed in the following sections. The first of these (section 2.2) is appropriate for ground analysis of complete time histories of loading data gathered at a fixed sampling rate and is referred to as 'the ground mode'. The second mode (section 2.3) is designated 'the snapshot mode' and is specifically designed for use in the real time environment. The latter mode is required since future systems for monitoring in-service loads must involve on-board processing of the loading data if acceptable analysis costs are to be maintained. The philosophy of 'the snapshot mode' provides the key to rapid assessment of fatigue damage accumulation during service usage at squadron level or indeed on the aircraft itself. The two modes of displaying the accumulation of fatigue damage illustrate different, but complementary features of the data, and therefore both have been developed for use in ground analysis of loads data.

The damage accumulation plot has been introduced above in the context of in-service monitoring of structural loads but it has a number of other important uses in the field of operational loads data analysis. These are discussed in some detail later in the report after specific examples have been presented which give the reader an appreciation of the potential usefulness of the display technique.

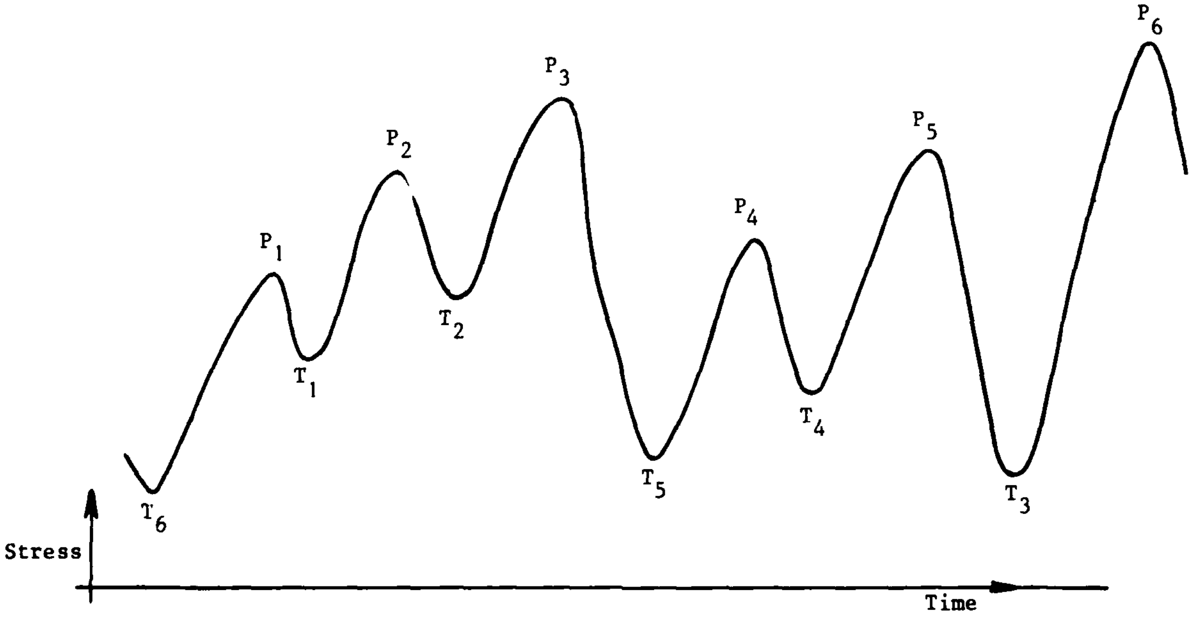
2 DISPLAY OF ACCUMULATION OF FATIGUE DAMAGE THROUGHOUT A FLIGHT

2.1 General remarks

In order to produce a plot of the accumulation of fatigue damage during the flight, it is necessary to have a load time history - measured or computed from response quantities[1] - which is appropriate for a particular feature of the structure. Secondly a representative fatigue damage algorithm must be available. The development in this Report proceeds on the basis that Miners Cumulative Damage Rule is applicable and that the relevant loading cycles are identified by a range-mean-pairs (rainflow) analysis[2] of the load time history. However the principle of forming damage accumulation plots can be adopted with other damage algorithms.

2.2 The damage accumulation plot: the ground mode

Suppose the time history illustrated below to be that of the load under consideration. In a range-mean-pairs analysis the peaks, P_i , would be paired with the troughs T_i , $i = 1,2,\ldots 5$, as structural loading cycles.



If the RAE range-mean-pairs (rainflow) algorithm[2] is used to analyse this waveform and the leftover waveform is treated by the 'reordered stack method' then P_6T_6 is identified as a loading cycle. The order of identification of the loading cycles is 1, 2, 4, 5, 3, 6. In the RAE algorithm the peak and trough values, which constitute a loading cycle, and their respective time of occurrence into the flight can, if required, be separately logged. This peak-trough file of loading cycles can be used to produce a graph of the accumulation of damage against time into flight. In this mode the identification of loading cycles is fully completed before any damage is evaluated. Thus various S-N curves can be used in the damage evaluation without the need to go back to the raw loads time history data.

The time associated with a given loading cycle, and thus a damage increment, can be one of the following:

- (i) the time of the peak
- (ii) the time of the trough
- (iii) the earliest time whether it be peak or trough
- (iv) the latest time whether it be peak or trough.

Thus appropriate ordering of the damage increments gives four possible presentations of the accumulation of damage against time. For components, such as fins, where there is little or no variation of mean load and no ground-air-ground cycle as such - all four presentations may be expected to yield similar results. However wing data may be expected to yield very different pictorial presentations of the accumulation of fatigue damage for the four procedures given above and all four are useful, particularly on transport type aircraft. These are illustrated in Fig 1 which shows data from a wing strain gauge during a flight with a grass strip landing in mid sortie. (The damage scales are non-dimensionalised and the S-N curve employed is appropriate to a structure with fretting fatigue problems.) The left hand illustration contrasts the effects of plotting the damage increments at the times of the earliest and the latest components of the loading cycle. The right hand illustration completes the quartet of possible representations by plotting the damage increments at the times of the peak and the trough of the loading cycle. If a given increment of damage (say AA') can be identified uniquely on all four presentations, it is possible to deduce the nature of the underlying load cycle components. This can usually only be done for the most damaging cycles, but it is just these cycles that the analyst is likely to want to detail in say load pattern recognition. Thus it can be seen that the damage increment AA' arises from a peak about 2 min after take-off which is paired with a trough during the final landing. The larger damage increment BB' arises from a trough soon after touchdown of the mid-sortie landing which is paired with a peak during the second airborne phase. These cumulative damage plots are dominated by these two ground-air-ground cycles: the other loading cycles in the load time history comprising some 28% of the total sortie damage.

2.3 The damage accumulation plot: the snapshot mode

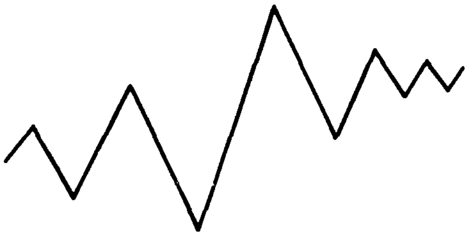
The graphical presentations of section 2.2 were created when the complete load time history was available at the end of the flight. Thus the full extent of all loading cycles was known before any damage calculation was attempted. The peak-trough timings can therefore be accurately determined. Clearly this presentation cannot be achieved in real time but an alternative display can be devised which, for most purposes, is equally useful. This is achieved by considering the damage algorithm in more detail.

At any time, during the range-mean-pairs (rainflow)[2] identification of loading cycles, the following data are available:

(i) the complete loading cycles already identified;

(ii) the current left-over waveform stack of peaks and troughs comprising the unterminated loading cycles and having the characteristic divergent-convergent envelope as shown in the sketch below, and

(iii) the last known data point which may or may not be a peak or a trough.



Typical left-over waveform stack

From these data it is possible to compute damage to date on the assumption that the flight terminates at that point in time. If this process is repeated at regular intervals throughout the flight then it is possible to construct, in real time, the accumulation of fatigue damage. This process is approximate in relation to that of section 2.2 because, of course, the flight did not terminate at the computation intervals and so the full extent of some loading cycles is not known, nor indeed is the eventual pairing of the peaks and troughs of the left-over waveform. Thus to evaluate the effects of different S-N curves it is probably expedient to start from the raw data and repeat the complete process since for very short computation intervals the number of words of analysed information may well exceed that of the raw data.

At the computation intervals, the procedure adopted here is as follows. Firstly, the damage due to the completed loading cycles is computed using basic S-N data. Secondly, the last data point, described above, is dismissed since its precise nature is likely to be quantified within the next few computation intervals. Thirdly, the damage due to the current left-over waveform is computed by the 'reordered stack method'[2] which effectively gives the average damage for that waveform were it to be repeated many times. Thus, for in-flight computation intervals, the flight is effectively terminated by a ground load level equal to the pre-take-off loading condition. This latter component of damage, when added to that from the complete load cycles, gives the total damage incurred to date. The two components are shown in Fig 2 for the same raw data of Fig 1. The complete cycles, left-over waveform and last data point are referred to as snapshots since the data stream being analysed is not corrupted by the intermediate damage calculation. The damage accumulation plots are illustrated for two different snapshot intervals: 1 min and 5 min. In fact the presentations in Fig 2 contain information which cannot be obtained from Fig 1. For instance there is a ready indication of what the sortie damage would have been were the sortie to have been terminated after the first landing at, say, 15 min after start of data. For this load time history, dominated as it is by two large loading cycles, the most useful graph is perhaps that for the total damage (Fig 2). However for many transport type aircraft flights, there is only one ground-air-ground cycle and it is not uncommon for this to be the only structurally significant loading cycle in the left-over waveform. In such a case the difference between the growth of damage from the complete load cycles and that of the total damage is then representative of the growth of the damage due to the ground-air-ground cycle.

The presentation of Fig 2 lacks the precise detail of 'the ground mode' display which the loads analyst might at times find useful. However it offers a useful alternative display for the operator or analyst who wishes to use the display to identify those flight phases giving rise to significant fatigue damage. The detail contained in 'the snapshot mode' can be increased by further reducing the snapshot intervals and in the limit the snapshot could be geared to the times of identification of a loading cycle which is above fatigue threshold. Thus in such a presentation increments in damage will be logged at a certain time into flight which post dates their occurrence. This limiting case of the snapshot mode is shown in Fig 3 for the raw data of Figs 1 and 2. Strictly speaking the limiting case should also show the growth of the total damage - from the left-over waveform - from data start to the time of the first accountable loading cycle. However, it is suggested that, for most practical purposes the coarser, equi-interval snapshots of Fig 2 provide sufficiently detailed information.

Although the snapshot concept was specifically developed for the real time airborne environment, it can be used with effect in ground analysis work. A snapshot ground analysis program developed from that of Ref 2 has been used to produce the snapshot data of this Report.

3 APPLICATIONS OF THE DISPLAY TECHNIQUE

3.1 Aircraft A

From the data presented in Fig 1, the analyst might well question the reasons for the difference in size of the loading cycles AA' and BB'. A significant feature is that for both these loading cycles, the troughs occur during a landing phase - that of BB' occurring very close to touchdown while that of AA' occurs some 2 min after final touchdown. The final landing - on a paved surface - has its lowest trough in wing strain during ground manoeuvring whereas that for the mid-sortie grass field landing occurred during the landing phase. This suggests that, for grass field operations, the landing may be structurally more severe than the take off run. In the example shown in Fig 1 this is certainly so - the damage increment occurring during the touch down phase, marked CC' on Fig 1, is much larger than that during the take-off run. In addition, the ground-air-ground cycle is increased thereby contributing to the increased size of

BB' over AA' . The deeper trough of the grass field landing is not the sole reason for the increase since a higher peak strain occurred in the second airborne phase than during the first (at times 22 min and 10 min respectively on Fig 1).

The deductions drawn above from the single grass field operation of Fig 1 are confirmed by the data presented in Fig 4 which shows the damage accumulation plot ('the ground mode') for a number of grass field operations. (Note the change of scale in Fig 4 compared with Fig 1.) Only the first take-off is from a paved surface. All the grass field landings shown are associated with larger increments of fatigue damage than the take-off run.

3.2 Aircraft B

A family of damage accumulation plots for a wing station of a large flexible aircraft, aircraft B, are used to illustrate how the display can be used to define fatigue damaging activities. Estimates of fatigue damage rates for those activities could be deduced from the graphs and used in rationalizing the structural usage of the aircraft against the operational need. The damage rates would, of course, need to be established over a larger number of flights than the subset illustrated here.

Fig 5 shows the damage accumulation plot for a flight involving manual precision station keeping during low level formation flying. The graph clearly illustrates the increasing difficulty of the task through its steadily increasing slope, until the formation is eventually broken and climb out initiated. The zero damage rate under autopilot in height lock at FL190 provides a sharp contrast between the formation flying and the final descent and landing. Viewed in conjunction with aircraft response data, the display can be used to highlight fatigue damaging flight conditions. In particular, in Fig 5, it can be seen that the highest damage rate during the formation flying is associated with large speed fluctuations which undoubtedly exacerbate a difficult control problem.

The components of the most damaging loading cycle of Fig 5 occur at times 1 min and 96 min after start of data. The component at time 1 min is during the take-off run and must, with the known instrumentation set up, constitute the trough. Thus in contrast to the information presented for aircraft A, the trough of the ground-air-ground cycle occurs during the take-off run.

Other flight documentation information can be used to relate the damage incurred to specific aircraft configurations on particular activities. For example, for aircraft B, fuel weight is documented at half hourly intervals throughout the flight. This information can be used to determine when the aircraft receives or dispenses fuel as illustrated in Fig 6. The periods of fuel dispensing can only be determined approximately because there is no indication though the aircraft response parameters that they are in progress! In contrast, the fuel receiving periods have a definite signature and can be determined accurately. On both flights of Fig 6 the ground-air-ground cycle comprises a trough during the take-off run which is paired with a peak during manual receiving. Again low damage rates under autopilot (height lock) cruise are evident and can be contrasted with those under manual control. However some damage is incurred under autopilot control when a change of flight condition is requested (see Fig 6 top illustration between times 135 and 140 min). Changes of flight condition invariably produce some damage. Several such changes under manual control are shown in Fig 7, Flight 4: the ground mode. In fact it is not uncommon for the highest peak strain in the wing to be met around top of climb as exemplified in 'the ground mode' data for both flights of Fig 7. Very high damage rates are achieved when change of flight condition is executed while flying in formation (*circa* 80 min into Flight 4 of Fig 7). Here over half the damage accrued for the whole 3½ h flight is attributable to a single 10 min period. The fatigue conscious operator may well question the operational need for such activities. Again in Flight 5 of Fig 7 approximately half the flight damage occurs during one phase - the final 50 min of circuits and rollers. Thus it can be seen that armed with the knowledge that the damage accumulation plot can yield, the operator can plan the structural usage of his aircraft in the light of his operational objectives and his sensitivity to fatigue costs. To achieve this he needs the information readily available.

The real-time 'snapshot mode', developed as a basis for future on-board monitoring systems does provide an equally vivid indication of these damaging flight phases as shown in Fig 7 which affords a comparison between the 'snapshot mode' and the 'ground mode' for Flights 4 and 5. The 'snapshot mode' also gives some indication of the time-wise position of the ground-air-ground cycle. As mentioned in section 2.3, in this mode, the growth of the largest cycle - in both flights of Fig 7 this is the ground-air-ground cycle - is the major component of the difference between the total damage and that from the terminated cycles. However, at times this difference also includes damage from the half cycles of the left-over waveform some of which in the fullness of time become terminated cycles. In Fig 7, such a situation exists in 'snapshot mode' data of Flight 4 from 85-180 min. Nonetheless the size of the eventual difference at the end of the flight can be traced back through the flight and is seen to be first present at about the time of top of climb.

3.3 Aircraft C

The damage accumulation plot can be used in a comparison of damage accumulation rates throughout the airframe and thus identify which flight phases are damaging for which component. Wing, fin and tailplane strain gauge data are compared in this way in Fig 8 using data supplied by BA plc. It is immediately evident from the presentation that as far as the empennage is concerned that fin and tailplane have their maximum rates of accumulation of fatigue damage in quite different flight régimes. Apart from the effects of the four isolated large loads, the wing suffers fatigue damage during the circuits. With such a display, the operator is immediately aware of the increased rate of consumption of fatigue life incurred on the wing and tailplane during the circuits and can, if needs be, plan accordingly. It is likely that the peak wing strain at 160 min and trough at 207 min are due to longitudinal manoeuvres associated with change of flight condition since the tailplane has damage increments at the same time. For this flight of aircraft C the ground-air-ground cycle comprises a trough during the take-off phase which is paired with the maximum peak strain which occurs during the final circuit and approach.

4 THE USES OF THE FATIGUE DAMAGE ACCUMULATION PLOT - A DISCUSSION

The examples of the previous section show that the damage accumulation plot is potentially very useful for the operator in planning a structurally efficient usage of his aircraft. They also show that damage rates for similar activities on different flights are more or less constant and are thus likely to be a property of the man/machine total system performance in that situation. Further, if the analysis is based on an instrumentation system which has a reproducible performance on all aircraft in the fleet, then one would expect similar damage rates for similar activities on different aircraft. Any significant disparity in damage rates should be questioned and a satisfactory explanation sought. However for effective fleet management the required information must be readily available.

An airborne microprocessor can be used to compute the cumulative damage at various intervals during the flight using the snapshot concept described in section 2.3. Already the implementation of in-flight range-mean-pairs (rainflow) counting of strain histories has been validated[3] in the operational environment. With the addition of a damage algorithm in the microprocessor software, the structural information for each snapshot interval is contained in 2 data words per channel analysed. Ideally these two components of damage per channel would be supplemented by some coarse indication of aircraft configuration *eg* flaps, airbrakes etc; and flight condition *eg* maximum and minimum height and speed during last snapshot interval, thus greatly increasing the usefulness of the damage accumulation data. From the standpoint of in-service monitoring of structural loads, the 'fatigue damage' snapshot concept dramatically reduces the amount of data that must be transferred from aircraft to ground. Automatic graphical presentation of the damage accumulation, aircraft configuration and flight condition data provides the necessary basis for fleetwide management of aircraft structures from a fatigue standpoint.

The role of the damage accumulation plot has been discussed above in relation to the *output* of an advanced fatigue load monitoring system. However it has an important role to play in the development of suitable *input* data streams for such a system. It must be stressed that the raw data for these fatigue load monitoring systems are relevant load time histories. These can be produced by direct measurement of strain or through combinations of flight parameter data[1] such as normal acceleration, roll acceleration, control angles, etc. If such parametric estimates of load can be formulated then the need for strain gauging is obviated. In terms of a fleetwide fit, this is a very attractive proposition but the costs of developing the parametric equations are likely to be very high. This is because the parametric equations are, for some components, valid over a very restricted range of flight conditions and aircraft configuration. There is therefore a need to define the flight conditions/flight activities that make substantial contributions to fatigue damage in the operational environment so that suitable parametric equations in those regions can be established.

The damage accumulation plot can be used by the loads analyst in directing his analysis resources to those flight regimes that are of the greatest importance in fatigue for a particular component.

The aforegoing discussion was concerned with future generation fatigue monitoring systems. The current fatigue meter, based as it is on the accelerometer has obvious merits in its simplicity and cheapness of fit. The counting algorithm employed in the device approximates to a range-mean-pairs analysis[4]. However, the device only produces useful statistics for loadings which correlate well with the monitored acceleration. In such circumstances, the counting rate of the device is calibrated against that of the desired loading. This is usually accomplished in an overall sense thus masking any disparity of counting rate in particular flight segments. A damage accumulation plot for both the actual fatigue damage and that deduced from the fatigue meter data would show when real damage is correlated with fatigue meter damage and could lead to a better management policy for the device.

Occasionally, operational loads data are collected for the purposes of establishing realistic loading sequences for a fatigue test. The damage display technique developed in this Report pinpoints which portions of the operational flying should be represented in the test. A number of different S-N curves, representing different structural features, can be used in the analysis to assess whether the critical flight phases are sensitive to the assumed fatigue resistance of the structure. Also the display can be used to identify commonly occurring patterns on isolated features within the data. Misrepresentation of such features in the test could lead to a substantial difference in the demonstrated fatigue life of the specimen. For example, the peak strain for the majority of flights may occur in a particular flight phase, *eg* early or late in the flight, when the aircraft is in a particular configuration. The damage accumulation plot offers a ready means of establishing norms and patterns within the data.

The fatigue damage accumulation plot is also of use in the design of structural load alleviation systems to establish on the one hand which parts of the flight envelope/operation can, cost effectively, be improved and on the other hand where the mathematical models must produce accurate estimates of loads. The same display technique can be used to evaluate a system design in all flight phases.

The damage accumulation plot has a potential use in the ground replay of flight data. Operationally acquired structural and aircraft response data are commonly recorded on data media that are not suitable data storage devices for computer analysis. The data are therefore in the first instance transferred to a more appropriate medium[5]. It is then common practice to produce analogue trace plots of the complete flight to check data integrity and as an aid to instrumentation system maintenance. It is suggested that early production of a damage accumulation plot can lead to a dramatic reduction in the amount of flight data replayed in analogue trace format by suppressing trace production in non-damaging flight phases. Any automatic analysis of flight data should include data validity checks such that the analysis being undertaken is not compromised by faulty data. However when using the damage accumulation plot to control analogue trace production only rudimentary data checking is necessary. Fatigue damaging sections of the flight will be displayed as response time histories and data quality and system integrity can thereby be assessed.

5 CONCLUSIONS

A technique for displaying the accumulation of fatigue damage throughout a flight has been described and used in a number of examples which demonstrate the power of the display. Two distinct modes of presenting the cumulative damage have been developed. One of these is designated 'the ground mode' and is suitable for situations where the complete load time history is available to the analyst. A timebase, introduced during the range-mean-pairs (rainflow) analysis, is utilized to match a damage increment due to a complete loading cycle to a specific time into flight. The second mode is called 'the snapshot mode' and is developed specifically for use in the real time environment. Here at regular intervals into the flight the current state of the range-mean-pairs (rainflow) analysis is used to compute the cumulative fatigue damage to date.

The damage accumulation plot is of potential use to anyone in the aircraft loads area who, for any reason, needs to define the flight conditions/flight activities that make substantial contributions to fatigue damage in the operational environment. Thus the display has a wide range of applications in the field of operational loads data analysis, the same display serving both the operator, the loads data analyst, the fatigue specialist and the control systems designer.

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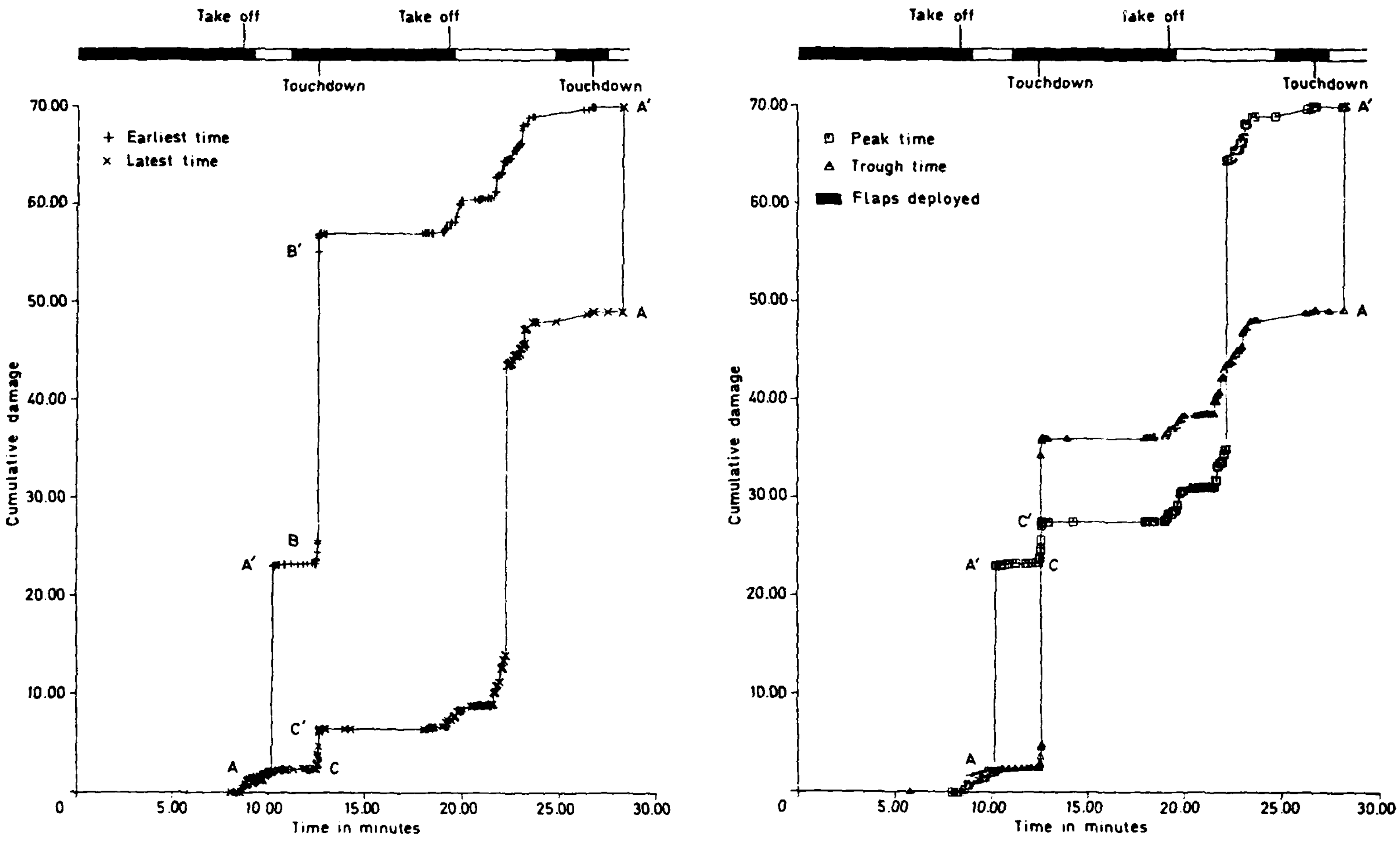

Fig 1 Aircraft A, Flight 1. Grass field mid-sortie landing; *damage accumulation — 'the ground mode'*

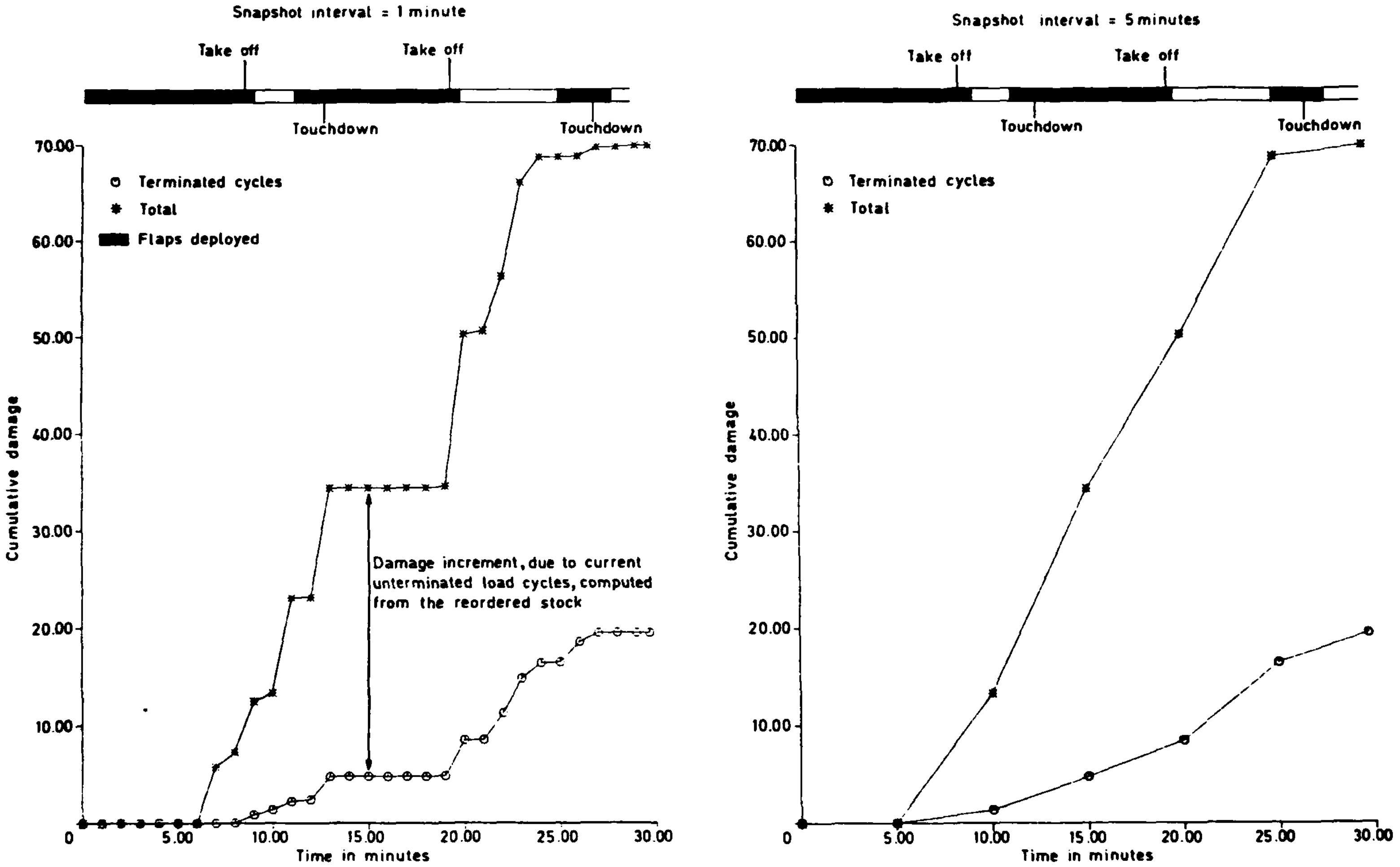

Fig 2 Aircraft A, Flight 1. Grass field mid-sortie landing; damage accumulation – 'the snapshot mode'

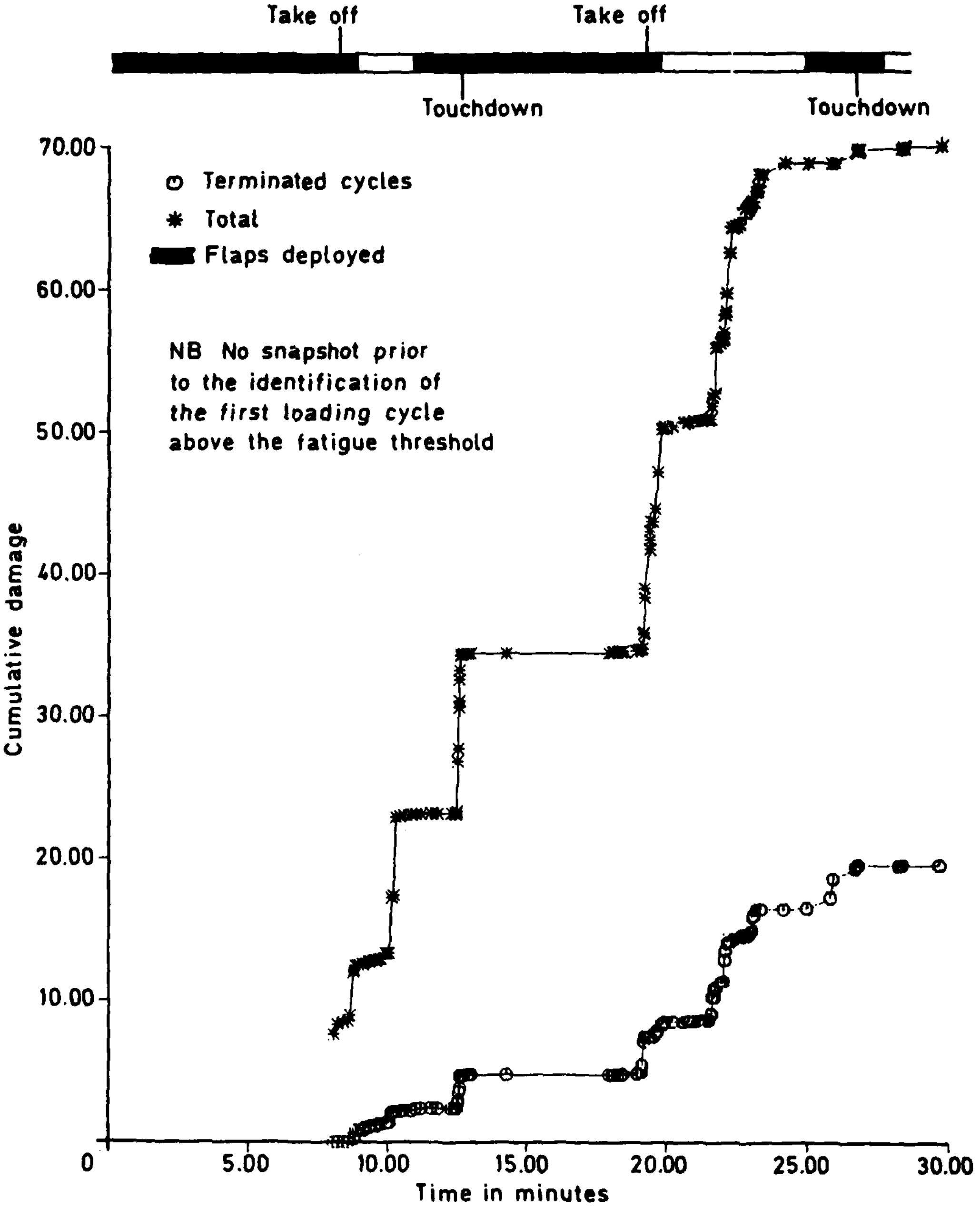

Fig 3 Aircraft A, Flight 1. Damage-accumulation plot – the limit of 'the snapshot mode'

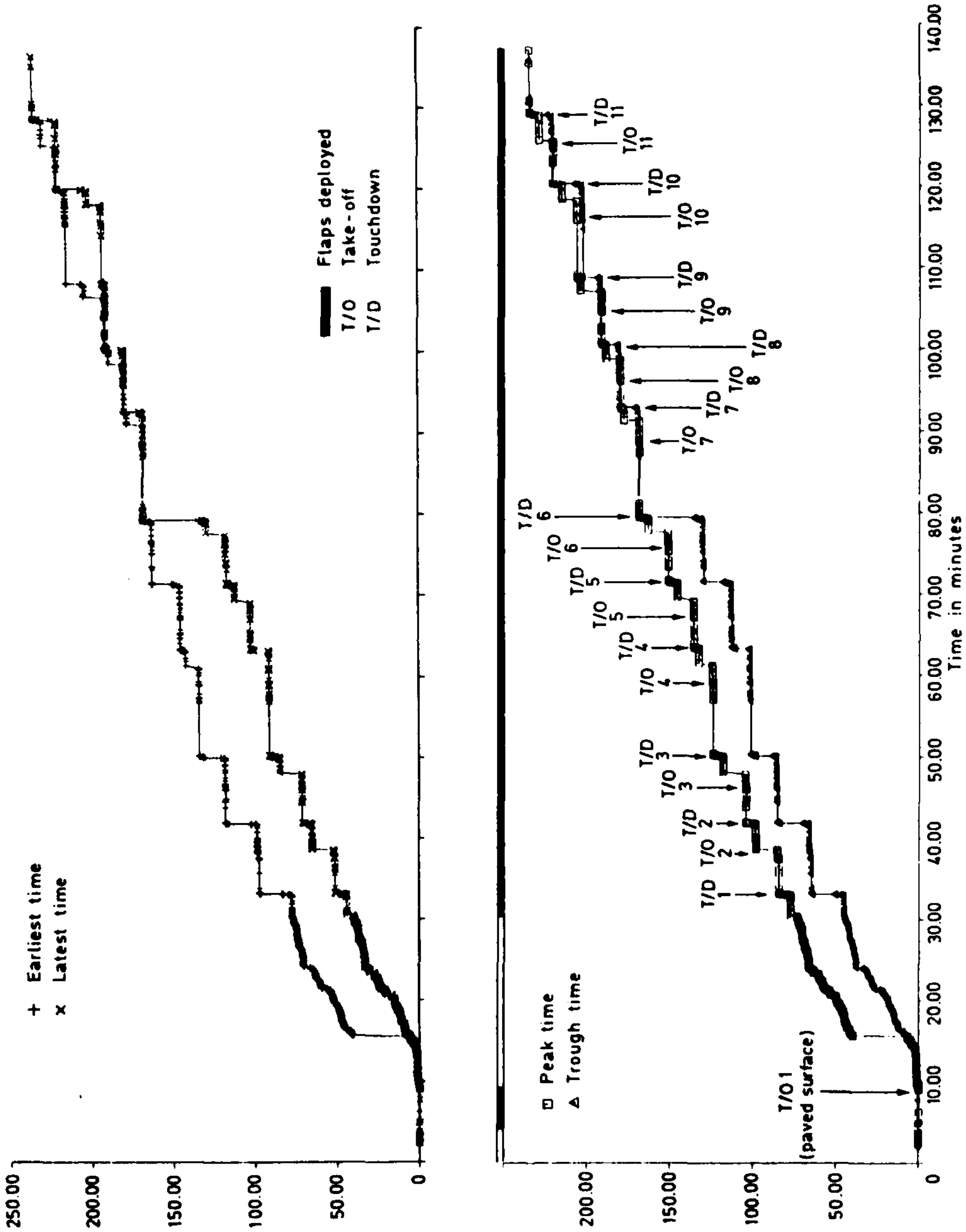

Fig 4 Aircraft A, Flight 2. Grass field operations

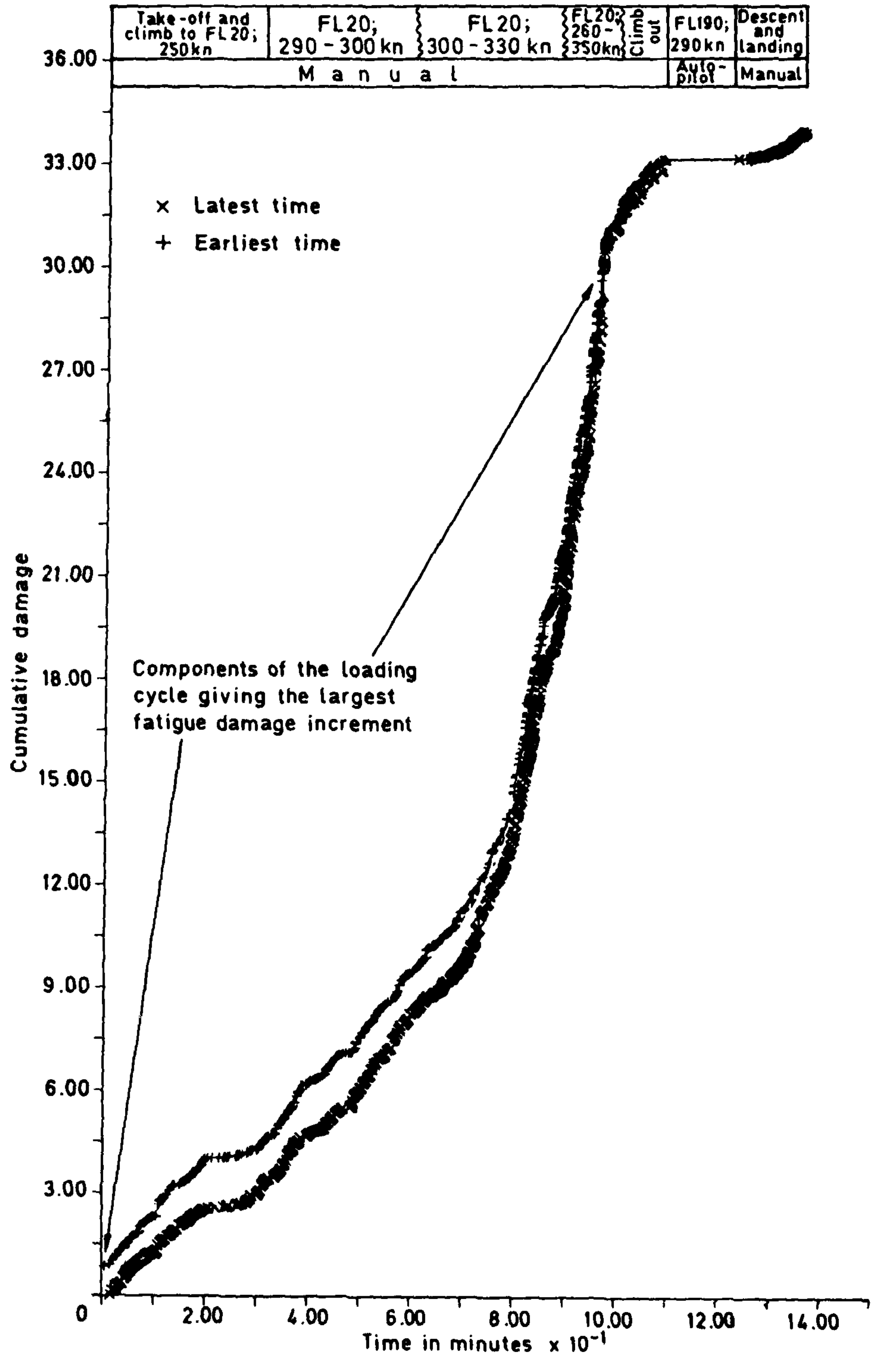

Fig 5 Aircraft B, Flight 1. Low level manual formation flypast

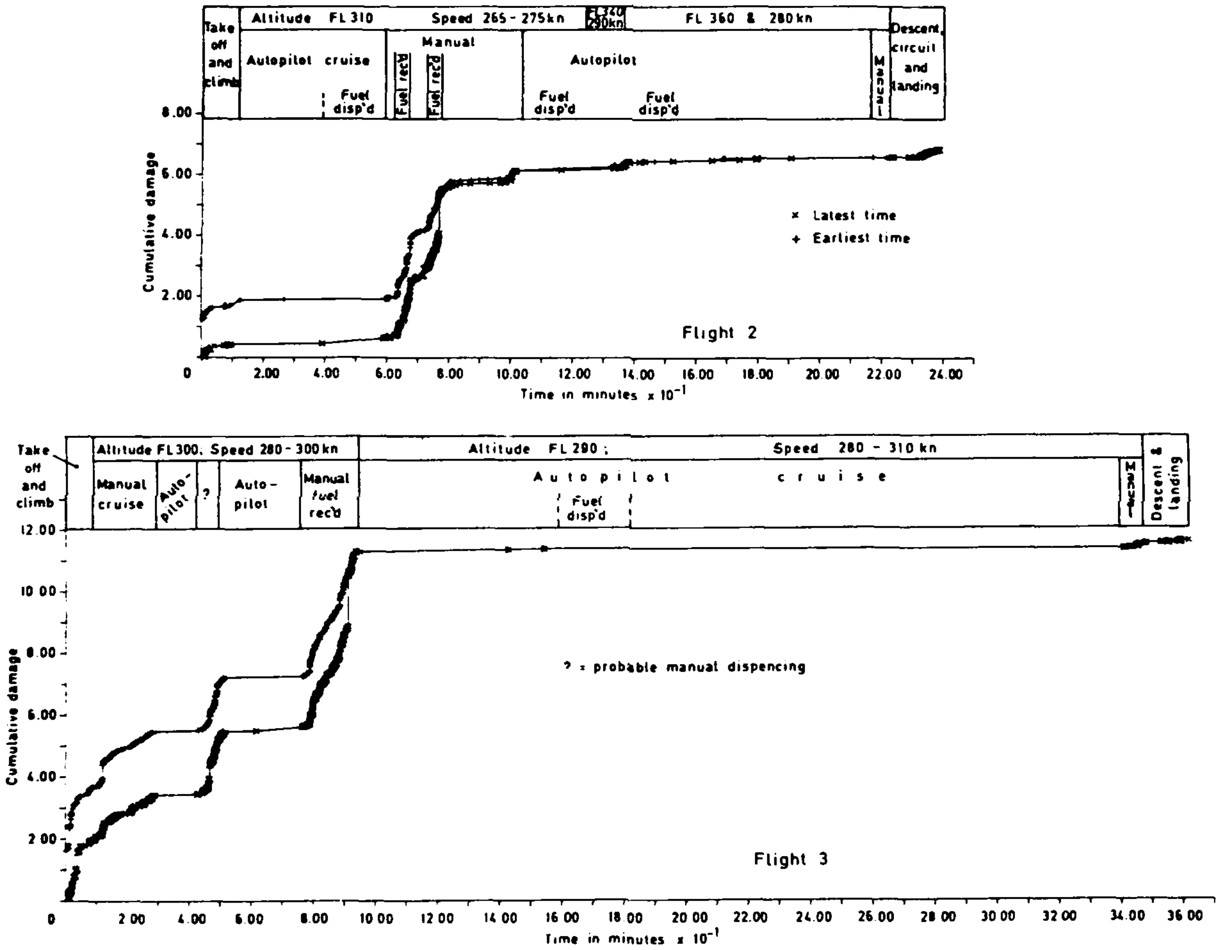

Fig 6 Aircraft B, Flights 2 and 3. Comparison between damage rates during fuel dispensation, fuel receiving, manual and autopilot (height lock) flying

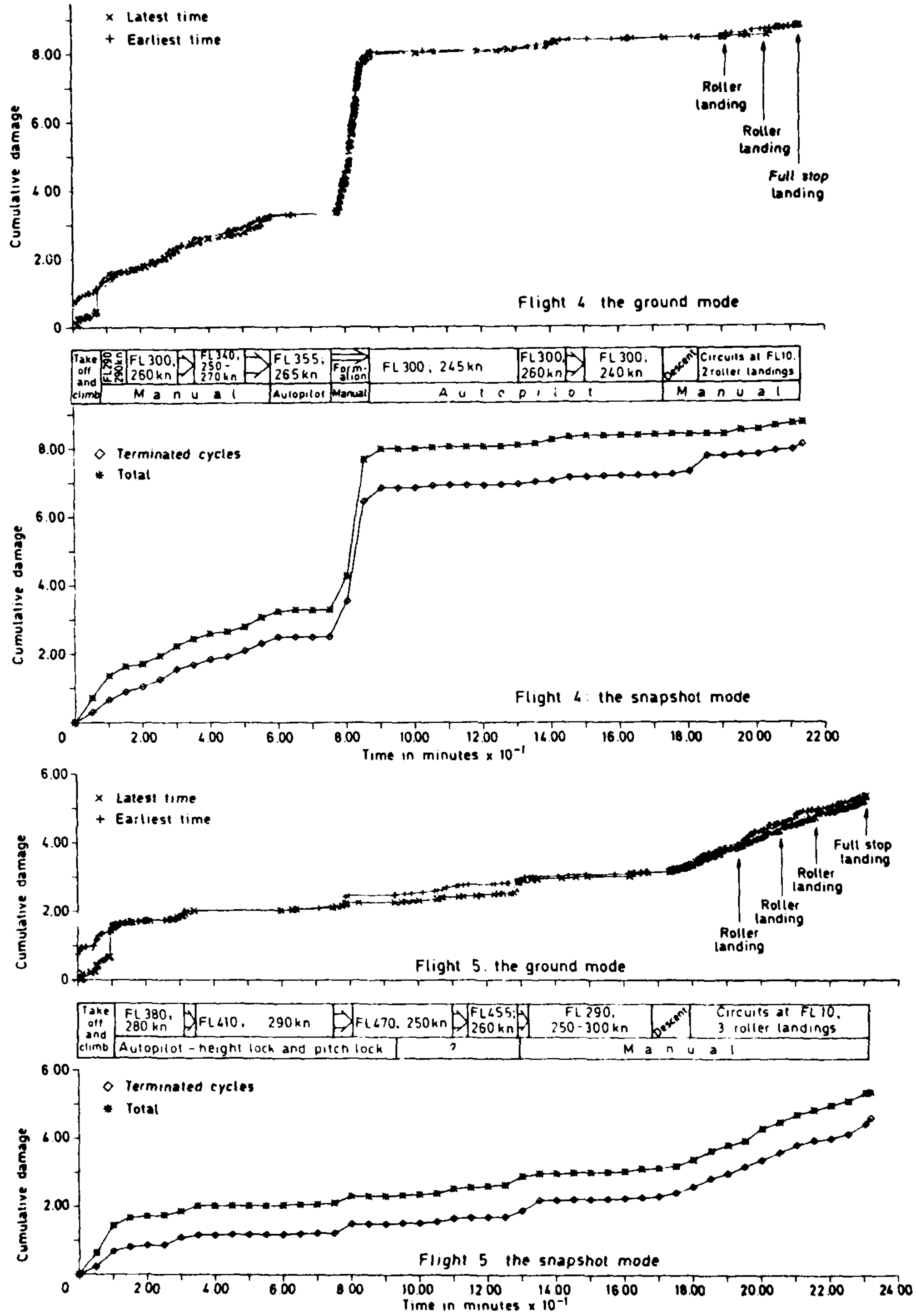

Fig 7 Aircraft B, Flights 4 and 5. A comparison of damage accumulation plots in the 'ground mode' and in the 'snapshot mode'

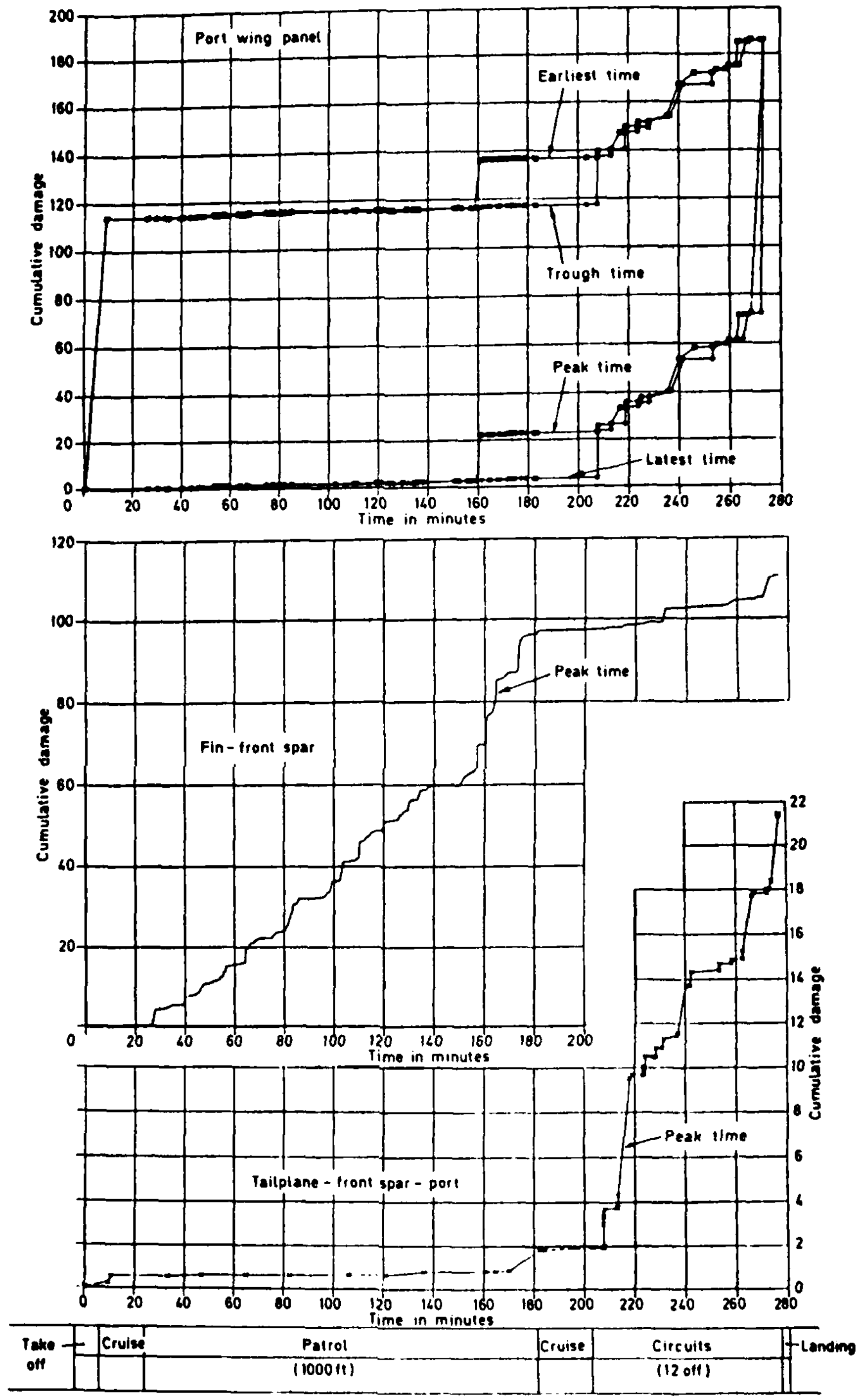

Fig 8 Aircraft C, Flight 1. Cumulative damage plots for aircraft major components

REPORT DOCUMENTATION PAGE

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17. Abstract

The concept of displaying the accumulation of fatigue damage against time into flight is described. Two distinct modes of presentation are described: one called 'the ground mode' is suitable for use in ground analysis of load time histories and the other designated 'the snapshot mode' can be used in the real time environment. Examples drawn from operational aircraft loads data are used to demonstrate the usefulness of the display. The damage accumulation plot permits a ready identification of those flight conditions/flight activities which give rise to substantial fatigue damage. Thus it can be used to identify the structurally relevant flight data and so reduce the quantity of data that needs to be analysed in an operational loads measurement programme. It has many uses in the field of loads data analysis and is of particular importance in advanced fatigue load monitoring systems, fleet management from a fatigue standpoint and in the specification of fatigue test loading sequences.

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